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(54) IMPROVED METHOD OF AND APPARATUS FOR THE INDUCTIVE MEASUREMENT OF FLUID FLOW

(71) We, FLOWTEC AG., a Swiss company of Sternenhofstrasse 21a, 4153 Reinach BL 1, Switzerland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

This invention relates to a method for inductive measurement of fluid flow using a periodically reversed magnetic field, in which the work signal is derived by sampling and holding the signal voltage at equal but oppositely poled values of induction of magnetic field and the difference between the stored sample values is formed. The invention also relates to apparatus for carrying out this measurement.

In magnetic induction fluid flow measurements there exists the problem that the measured voltage denotive of the fluid flow has superimposed upon it a disturbing direct voltage (asymmetric voltage), which has its origin in different electro-chemical equilibrium potentials. The disturbing voltage may attain values which are substantially greater than the measured voltage.

In addition there may also be superimposed upon the measured voltage alternating current components, which originate from the mains and have frequencies which correspond to the mains frequency or its harmonics.

In the known methods of the kind initially described the magnetic field is periodically changed between two equal values of induction of opposite signs. Use is made of the fact that the measured voltage changes its polarity with the magnetic field, while the asymmetrical voltage retains its polarity. There is thus attained by sampling at the one induction value the sum of the measured and asymmetrical voltage and by sampling at the other induction value the difference of the asymmetrical voltage

minus the measured voltage. From the difference between the two stored sampling values there is thus obtained a measurement signal free from asymmetrical voltages. This method however makes the assumption that the asymmetrical voltage does not alter within the measurement cycle, since otherwise the alteration appears as an error in measurement. In addition the asymmetrical voltage must not assume too large a value, since otherwise the linear range of the measurement amplifier may be exceeded. Also for large values of the asymmetrical voltage great demands are made on the accuracy of the difference-forming circuits, since any error directly affects the measured value obtained as the difference.

It is also known, instead of a magnetic field reversed between two opposite values of induction to employ a unidirectional field periodically turned on and off. In this case with the magnetic field switched off the asymmetrical voltage is sampled and stored and with the magnetic field turned on the sum of the measurement and asymmetrical voltages is likewise sampled and stored.

The invention is directed to providing a method with which the electro-chemical disturbing voltages in the inductive measurement of fluid flow may be automatically compensated in a simple manner and at little cost, if they alter within the measurement cycle, in which no electro-chemical voltages are formed with the fluid stationary and in which over-driving of the amplifier by too-large an asymmetrical voltage is prevented.

Accordingly the method of the invention comprises, forming, between each two successive magnetic field impulses of opposite polarity an interval in which the magnetic field is zero, generating in a compensating time interval in each magnetic field interval at a constant time interval preceding the next sampling of the signal voltage, a

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compensation voltage which reduces to zero the signal voltage in the compensating time interval, the compensating value voltage generated in the compensating time interval being stored and employed up to the next compensation time interval.

The method according to the invention depends on the fact that a time variant asymmetrical voltage, if a linear alteration is assumed, starting from the value zero at the end of the compensation time interval always assumes the same value by the time the next sampling interval is reached. The signal voltages sampled in cyclic succession for the opposed values of induction thus always contain the same component of asymmetrical voltage, which is eliminated when the difference between the two signals is formed.

Since in addition the asymmetrical voltage does not attain excessive values between two compensation time intervals, which are separated by a time interval which corresponds to half of the measuring cycle, no over-driving of the amplifier through the asymmetrical voltage can occur. Since in the method according to the invention periodic reversal of the magnetic field is employed, the advantage is retained that with stationary fluids no electro-chemical voltages are formed, as is the case when a wholly unidirectional field is employed or when a unidirectional field is switched on and off. Since in addition the component of the asymmetrical voltage in each sampled value is small as compared with the measurement voltage component, the forming of the difference between successive signals requires only limited accuracy.

A further substantial advantage of the method according to the invention consists in that for the same sensitivity, a lower power consumption is required in comparison to the known method with reversed unidirectional field or a unidirectional field which is switched on and off, because of the intervals in which the magnetic field is zero.

Apparatus according to the invention for inductive flow measurement of an electrically conductive fluid flowing in a pipe, includes a magnetic field generator, which generates a periodically reversed magnetic field passing through the pipe perpendicular to the direction of flow, two electrodes arranged within the pipe, which are connected with signal inputs of a measuring amplifier, sample and hold circuits which are connected to the output of the measuring amplifier and which are controlled by a control arrangement so that they sample the output voltage of the measuring amplifier at mutually equal values of induction in opposite polarity, and store the sample values until the next sampling, and a circuit arrangement for forming the difference of

the two stored induction values and wherein the magnetic field generator is so controlled that between any two successive magnetic field impulses of opposite polarity there exists an interval in which the induction is zero, and that a compensation input of the measuring amplifier is connected with the output of a storage control circuit which, during compensation time intervals each occurring at a constant time interval before the next subsequent sampling of the signal voltage is connected with the output of the measuring amplifier so as to form a compensating voltage value which controls the output voltage of the measuring amplifier to the value zero and which maintains this compensation voltage value at the compensation input of the measuring amplifier until the next compensation time interval.

An advantageous extension of the arrangement according to the invention consists in that the control circuit forms the compensation voltage value by integration of the output voltage of the measuring amplifier existing in the compensation time interval, and that the duration of the compensation time interval is equal to one period of the mains frequency of a multiple thereof. This extension allows the disturbing alternating components of the mains frequency or one of its harmonics, as well as in case of need also alternating components of which the frequency is a fraction of the mains frequency, to be automatically eliminated. Preferred features and advantages of the invention will be apparent from the following description of embodiment thereof, given with reference to the accompanying drawings in which:

Figure 1 shows a schematic general view of an arrangement for inductive fluid flow measurement in accordance with one invention;

Figure 2 shows a simplified block diagram of the controlled arrangements for the magnetic field coil of the arrangement of Figure 1;

Figure 3 shows the block diagram of the signal processing arrangement of the arrangement of Figure 1;

Figure 4 comprises waveform diagrams used to explain the mode of operation of the arrangement for Figures 1 to 3; and

Figure 5 shows diagrams to a larger time-scale for explaining the mode of operation of the arrangement according to the invention.

Figure 1 shows schematically a pipe 1, through which an electrically conductive fluid flows perpendicular to the plane of the drawing. A magnetic field coil 2, which for reasons of symmetry consist of two equal halves arranged on either side of the pipe 1, generate within the pipe a magnetic field B1, B2 passing perpendicularly to the axis of

the pipe. Within the pipe 1 there are arranged two electrodes 3 and 4, at which an induced voltage can be tapped off, which is proportional to the mean velocity of flow of the electrically conductive fluid through the magnetic field. The electrodes 3 and 4 are connected with the two inputs 5 and 6 respectively of a signal processing arrangement 7, which provides at its output 8 a signal appropriate for further processing, which is a measure of the velocity of flow. The signal processing and control arrangement provides at two further outputs 9 and 10 control signals which are applied to the two inputs 11 and 12 of a coil drive arrangement 13. The two coil halves 2 are connected in series to the outputs 14 and 15 of the coil drive arrangement 13.

One embodiment of the coil drive arrangement 13 is shown schematically in Figure 2. It contains four switches 16, 17, 18, 19 which are connected after the manner of a bridge circuit, the magnetic coil 2 lying in a bridge diagonal, while the other bridge diagonal is connected in series with a constant current generator 20 to a direct voltage source 21. The direct voltage source 21, which may for example provide a voltage of 24 volts, can either be a mains-fed unit or a battery.

The switches 16 to 19, which in practice are naturally electronic switches, are actuated in diagonally opposed pairs by signals applied to the input terminals 11 and 12.

If an impulse is applied to input 11, the two switches 16 and 18 are closed, which lie in diametrically opposed branches of the bridge; in this case the current I delivered by the constant current generator 20 flows in the direction of the arrow B1 through the magnetic coil 2, so that this generates within the tube 1 a magnetic field B1, of which the direction is indicated in Figure 1 by the arrows shown in full line. If an impulse is applied to input 12, the two switches 17 and 19 are closed so that the current I applied to the bridge circuit flows in the opposite direction through the magnetic coils 2, as is indicated by the broken-line arrow B2; as a result the magnetic field B2 generated in the pipe 1 has the direction indicated by the broken-line arrow. The inductions B1 and B2 have the same value, but are of opposite signs. When an impulse is applied to neither of the inputs 11 and 12, all the switches are opened and the magnetic field in the pipe 1 has zero induction value.

Figure 3 shows a more detailed circuit diagram of the signal processing and control arrangement 7 of Figure 1. The two input terminals 5 and 6 are the inputs of a measuring amplifier 22 constructed as a difference amplifier, to which the signal voltage arising between the electrodes 3 and 4 is thus applied. To the output of the

measuring amplifier 22 there are connected two sample and hold circuits 23 and 24, the sample and hold circuit 23 being connected directly and the sample and hold circuit 24 by way of an inverter 25, which inverts the polarity of the output signal of the measuring amplifier 22. For simplicity it is indicated that the sample and hold circuit 23 contains a switch S1, which is closed by a signal applied to a control input 26 and then connects a storage capacitor C1 by way of a resistance R1 with the output of the measuring amplifier 22, so that the storage capacitor C1 charges to a voltage which depends upon the output voltage of the measuring amplifier 22. The circuit elements R1, C1 together form an integrating circuit, that integrates the output voltage of the measuring amplifier 22 during the time of closure of the switch S1. The output of the sample and hold circuit 23 is connected with the input of a buffer amplifier 28, which prevents the capacitor C1 from being discharged after the opening of the switch S1; the sampled voltage stored on the capacitor C1 thus remains available at the output of the buffer amplifier 28 until the next closure of the switch S1.

In the same manner the sample and hold circuit 24 contains a switch S2, which is closed by a control signal applied to a control input 27, as well as a storage capacitor C2, which together with a resistance R2 forms an integrating circuit, that integrates the output voltage of the inverter 25 during the time of closure of the switch S2. The charging voltage on the capacitor C2 attained after the opening of the switch S2 remains available at the output of a buffer amplifier 29 connected to the output of the sample and hold circuit 24 until the next closure of the switch S2.

The outputs of the two buffer amplifiers 28 and 29 are connected by way of summing resistances 30 and 31 respectively with the inverting input of an operational amplifier operating as a summing amplifier, in the negative feedback circuit of which there is connected a resistor 33 in parallel with a capacitor 34. The output of the operational amplifier 32 corresponds to the output 8 of the signal processing and control arrangement 7.

The measuring amplifier 22 includes an additional compensation input 35, which is connected to the output of a storing control circuit 36. As an example it is indicated that the storing control circuit may contain an operational amplifier 37, which by means of a capacitor 38 in the negative feedback circuit in conjunction with an input resistor 39 is connected as an integrator. The non-inverting input of the operational amplifier 37, acting as a reference input, is connected to earth. The input resistance 39 is con-

5 nected in series with a switch S3 to the
output of the measuring amplifier 22. It may
thus be seen that if the switch S3 is closed
the operational amplifier 37, develops an
output voltage which is applied to the
compensating input 35 of the measuring
amplifier 22 and has a value such that the
output voltage of the measuring amplifier 22
is controlled to the value zero. When the
10 switch S3 is open the operational amplifier
37 retains the compensation voltage value
developed until the next closure of the
switch S3.

15 A control circuit 41 controlled by a clock
40 provides at three outputs the control
signals for the switches S1, S2, S3; two
further outputs of the control circuit 41
correspond to the output 9 and 10 of Figure
1, at which there are provided the control
20 circuits for the coil drive arrangements 13.

If the described arrangement is fed from
the main, the clock 40 may have a synchronizing
input 42, through which it may be
synchronized by the main supply. This
25 synchronizing arrangement may be omitted
in a battery-driven apparatus.

The mode of operation of the above
described circuit will be explained with
reference to Figures 4 and 5.

30 Diagram A of Figure 4 shows the control-
led impulses at the output 9 and diagram B
shows the control impulses at the output 10
of the signal processor 7 of Figure 1.
Because of the above-described mode of
operation of the coil drive arrangement 13
35 (Figure 2) the magnetic field in pipe 1 thus
assumes alternately the induction values B1,
and B2 represented in diagram C of the
Figure 4, between which there exists an
interval in which the magnetic field has the
induction value zero. The period, which is
equal to the duration T_M of a measuring
40 cycle, is large compared with the period of
the mains frequency; the signals may be
obtained for example from the mains fre-
quency by digital frequency division by the
dividing factor 32, so that for a mains
45 frequency of 50 Hz the measuring cycle has
duration T_M of 640 ms; this corresponds to a
frequency of field generation of 1.5625 Hz.
In the illustrated example it is assumed that
in each period the two magnetic field
impulses as well as the intervals lying
50 therebetween all have the same duration,
which in the above-given numerical example
thus amounts to 160 ms.

The diagrams S1, S2 and S3 illustrate the
control impulses which are provided by the
control circuit 41 for actuation of the switch-
es S1, S2 and S3 respectively of Figure 3.
The control impulses are substantially shorter
than the control impulses of diagrams A
and B generated for controlling the magne-
65 tic field and in consequence also substantial-
ly shorter than the magnetic field impulses

generated by the magnet coil 2. Preferably,
the duration of the sample control impulses
S1, S2 and the compensation control im-
pulse S3 are similar in relation to the period
of the mains voltage; in a preferred embod-
70 iment they amount for example to 40 ms,
that is to twice the mains period. For clarity
diagram A of Figure 5, shows in a larger
time-scale, the mutual timings of the magne-
tic field impulses B1, B2 and control im-
75 pulses S1, S2, S3 for one period. The
sampling control impulses S1 fall within the
positive magnetic field impulse B1 and the
sampling control impulses S2 fall within the
negative magnetic field impulses B2. They
preferably lie in the region of the trailing
end of these impulses, so that relations have
become stationary in the sampling time
interval and possible initial oscillatory pro-
cesses have subsided. In the above-given
80 numerical example each sampling control
impulse S1, S2 may commence at a time
interval 100 ms after the beginning of the
corresponding magnetic field impulse B1 or
B2, so that it ends 20 ms before the end of
90 the magnetic field impulse.

The compensation control impulses S3
fall within the intervals between each two
successive magnetic field impulses. They
begin for example likewise at a time interval
of 100 ms after the end of the preceding
magnetic field impulse, so that after the end
of each compensation control impulse S3
there remains time interval of 20 ms before
the beginning of the succeeding magnetic
100 field impulse. Between the end of each
compensation control impulse S3 and the
beginning of the next sampling control
impulse S1, S2 there thus exists always the
same time interval of 120 ms.

Diagrams B of Figure 4 shows the wave
form of the signal voltage obtained by the
super position of disturbing direct voltage
 U_S and measurement voltage U_M for the
case of a disturbing direct voltage U_S con-
stant with time, which is assumed to be
smaller than the measurement voltage U_M .
In this diagram the sampling effected by the
sampling pulses S1, S2 is also indicated, it
being assumed that the compensation circuit
with the storage control circuit 36 is not
115 present. Diagram E of Figure 4 shows under
the same assumptions the relations for the
case of a disturbing direct voltage U_S
varying with time. Finally Figure 4 repre-
sents the mode of operation of the compen-
sation circuit for the case corresponding to
diagram E. For the sake of clarity the
diagrams D, E and F for one cycle of
120 measurement are shown to a larger scale in
Figure 5.

In the case of diagram D, there exists
during intervals in the magnetic field a
constant disturbing direct voltage U_S , upon
which a positive-going measurement voltage
130

5 U_M is superimposed during the positive magnetic field pulses B1, and a negative-going measurement voltage U_M during the magnetic field pulses B2. Since the sampling
10 always relates to zero level, the value sampled during the sampling S1 is $U_S + U_M$ and the value sampled during the sampling pulses S2 is $U_S - U_M$. As a result of the inversion by the inverter 25 and the subsequent summing operation, the difference of the two sampled values is formed:

$$U_S + U_M - (U_S - U_M) = 2 U_M.$$

15 The disturbing direct voltage U_S is thus eliminated by this difference formation.

20 If, on the other hand, the disturbing direct voltage U_S alters with time, as is illustrated in diagram E, complete compensation of the disturbing direct voltage by differencing is no longer possible. During sampling by the sampling pulses S1 a disturbing direct voltage U_{S1} is present, so that the sampled value $U_{S1} + U_M$ is stored.
25 During sampling by the sampling pulses S2 the disturbing direct voltage has increased by the amount ΔU_S ; the sampled values $U_S + \Delta U_S - U_M$ is thus stored. The ensuing formation of the difference thus yields:

30
$$U_{S1} + U_M - (U_{S1} + \Delta U_S - U_M) = 2 U_M - \Delta U_S.$$

35 The measurement is also affected by an error, which is equal to the alterations ΔU_S of the disturbing direct voltage between the two successive samplings. Diagram E of Figure 4 also allows a further disadvantageous consequence of the varying disturbing voltage to be recognised: the sum of the disturbing direct voltage and the measurement voltage can rapidly assume very large values, which exceed the linear modulation range of the measuring amplifier. When this occurs measurement is no longer possible. If
40 in addition the disturbing direct is large compared with the measurement voltage, errors in the formation of the difference very greatly affect the accuracy of the measurement results obtained.

50 Diagram F of Figure 4 and 5 show how the phenomena described above may be avoided by the operation of the storing control circuit 36 in combination with the particular kind of field drive employed.
55 Each compensation control impulse S3 causes the output voltage of the measurement amplifier 22 to be regulated to zero during a compensation time interval T_K which occurs shortly before the beginning of each magnetic field impulse. Since this regulation is effected during the intervals in the magnetic field, it operates only on the disturbing direct voltage existing at this
60 point in time. After the end of the compen-

sation time interval T_K the disturbing direct voltage then alters in accordance with the conditions prevailing, starting from the value zero. At sampling by the sampling pulse S1 it has attained a certain value ΔU_S .
70 Thus in this sampling time interval the sample value $\Delta U_S + U_M$ is sampled and stored.

75 Before the subsequent negative magnetic field impulse B2 the output voltage of the measurement amplifier 22 is again controlled to zero during a compensation time interval T_K .

Thereafter it rises again, starting from this value zero. If a constant linear alteration of the disturbing direct voltage is assumed, it again attains the same value ΔU_S at the time of sampling by the sampling control impulse S2 so that in this sampling time interval the sample value $\Delta U_S - U_M$ is sampled and
85 stored. The subsequent formation of the difference between the sampled values then gives:

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$$U_S + U_M - (\Delta U_S - U_M) = 2 U_M$$

it may thus be seen that the disturbing direct voltage is completely compensated, although it alters with time.

95 It is also to be seen that the disturbing direct voltage can always have only a small value, since it is returned to zero value during each half of the measuring cycle, from which it may be perceived that it does not alter greatly in this space of time. There is thus no danger of over-driving of the measurement amplifier.

100 Finally, the disturbing direct voltage ΔU_S to be eliminated at each formation of a signal difference always remains small in relation to the measurement voltage U_M so that accuracy of the difference formation affects the accuracy of measurement only insignificantly.

105 Because the signals sampled by the control impulses S1, S2 and S3 are always integrated over the duration of a time interval of 40ms, that is equal to two periods of the mains frequency, the superimposed disturbing frequencies, which are a multiple
110 of half the mains frequency (25 Hz), are made ineffective, since their direct current mean value is zero for the sampled signal.

115 The choice of the very low working frequency, which is only a fraction of the mains frequency and in the example given is 1.5625 Hz for a mains frequency of 50 Hz, yields several advantages. On the one hand there is, between the turning of the coil current and the sampling of the signal voltage sufficient time for initial oscillations to decay and steady conditions to result. On the other hand, at such low frequencies the coils may be regarded as practically pure
120 resistances, so that no large amount of

reactive power is necessary.

The coil currents and the magnetic fields generated by them have for simplicity been illustrated as rectangular impulses. The described method is however, independent of the waveform of the coil currents and magnetic fields. Even with rectangular drive pulses, because of the self-inductance of the coils, in general a more trapezoidal wave form of the coil currents will result.

WHAT WE CLAIM IS:

1. A method for inductive flow measurement using a periodically reversed magnetic field, in which the useful signal is obtained by sampling and storing the signal voltage at equal but opposite values of induction of magnetic field and forming the difference of the stored sample values, wherein there is formed between each two successive magnetic field impulses of opposite polarity an interval of which the magnetic field is zero, there being generated in a compensation time interval within each magnetic field interval at a constant time-interval before the next subsequent sampling of the signal voltage, a compensation voltage which restores the signal voltage during the compensation time interval to zero value, and that the compensation voltage value developed during the compensation time interval is stored and is employed until the next compensation time interval.

2. Apparatus for inductive flow measurement of an electrically conductive fluid flowing in a pipe, including a magnetic field generator which generates a periodically reversed magnetic field passing through the pipe perpendicular to the direction of flow, two electrodes arranged within the pipe, which are connected with signal inputs of a measuring amplifier, sample and hold circuits which are connected to the output of the measuring amplifier and are controlled by a control device so that they sample the output voltage of the measurement amplifier at mutually equal values of induction in opposite polarity, and store the sample values until the next sampling, and a circuit arrangement for forming the difference of the two stores induction values and wherein the magnetic field generator is so controlled that between any two successive magnetic field impulses of opposite polarity there exists an interval in which the induction value is zero, and that a compensation input of the measuring amplifier is connected with the output of a storage control circuit which, during compensation time intervals each occurring at a constant time-interval before the next subsequent sampling of the signal voltage is connected with the output of the measurement amplifier, so as to form a compensation voltage value which restores the output voltage of the measurement

amplifier to the value zero and maintains this compensation voltage value at the compensation input of the measurement amplifier until the next compensation time interval.

3. Apparatus in accordance with claim 2, wherein the control circuit forms the compensation voltage value by integration of the output voltage of a measurement amplifier existing during the compensation time interval, and that the duration of the compensation time interval is equal to one period of the mains frequency or to a multiple thereof.

4. Arrangement in accordance with claim 2 or claim 3, wherein each sample and hold circuit forms the stored sampled value by integration of the output voltage of the measurement amplifier existing during a sampling time interval, and that the duration of each sampling time interval is equal to one period of the mains frequency or to a multiple thereof.

5. Apparatus in accordance with any one of claims 2 to 4, wherein the magnetic field generator contains a magnetic field which is connected in a diagonal of a bridge circuit contains a switch in each bridge branch, the other bridge diagonal being connected to a constant current source and a control arrangement being arranged alternately to close two switches arranged in diametrically opposite bridge branches, and that all the switches are opened in intervening intervals.

6. A method of fluid flow measurement substantially as herein described with reference to the accompanying drawings.

7. Apparatus for fluid flow measurement substantially as herein described with reference to Figures 1, 2 and 3 of the accompanying drawings.

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Fig.1

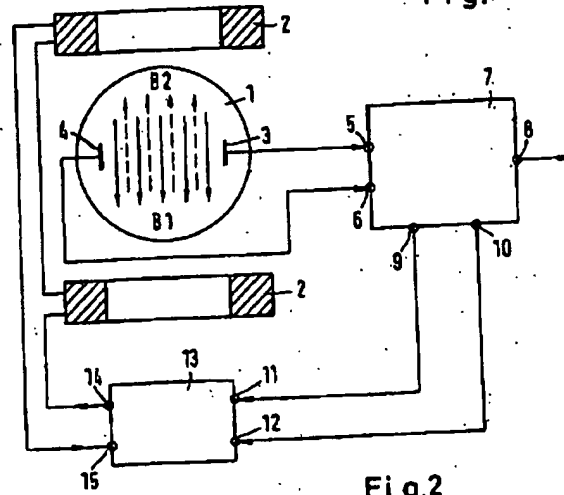
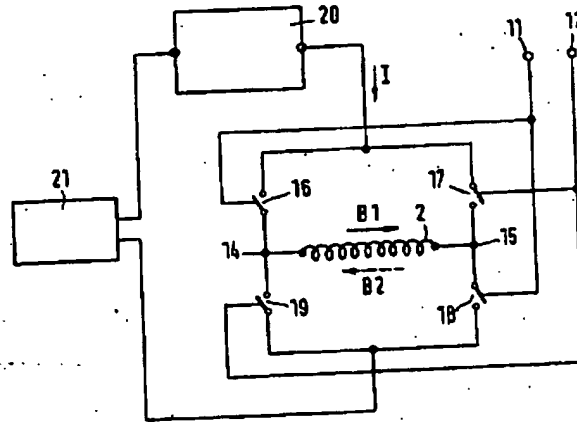


Fig.2



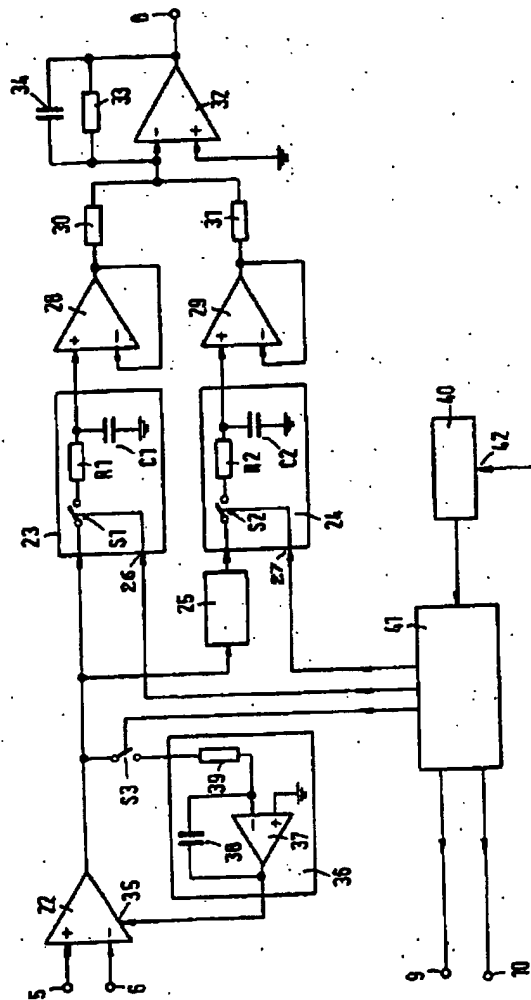
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Fig.3



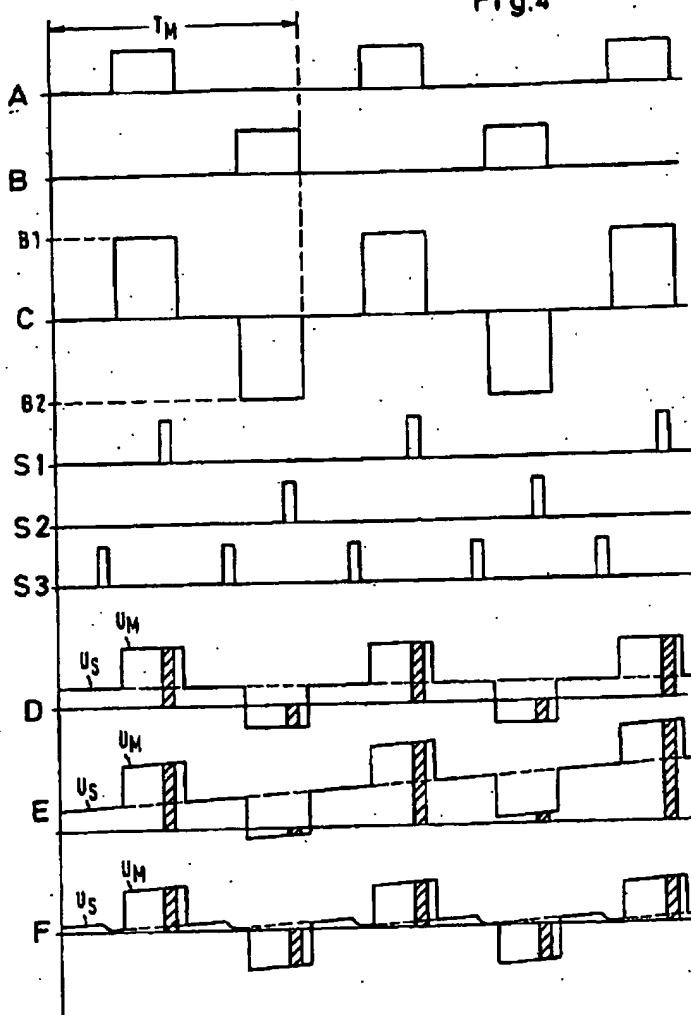
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Fig.4



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Fig.5

